ANALYSIS QUANTUM EFFICIENCY SPECTRUM OF NEA-GaAs PHOTOCATHODE

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Abstract

Negative Electron Affinity (NEA) GaAs photocathode has important rolls in the advanced accelerators such as ERL(Energy Recovery Linac), ILC(International Linear Collider), etc. because of the polarization and high brightness. Significant decline of Quantum Efficiency (QE) has been observed regarding to time and extracted beam charge and it could be a bottle neck in a real operation. To have studied the QE decay, we had measured temporal evolution of QE spectrum of NEA-GaAs photocathode, i.e. QE as a function of photon wave length. Based on an electron emission model from NEA cathode where the NEA surface is represented with a potential wall, we analysed the spectra and extracted the surface potential evolution. According to the analysis, the electron affinity did not vary (at least, stay at negative during experiment). We found that the spectrum evolution can be interpreted as increasing the wall thickness.

INTRODUCTION

For future accelerator projects, e.g. ERL, and ILC, electron source is one of the most important components that decide the total performance. ERL needs an electron source which provides low emittance, high current, high QE, and long life time. To obtain the electron beam which satisfies these requests, a high voltage DC gun using NEA-GaAs photocathode has been developed [1]. Energy level of the bottom of the conduction band of nominal semiconductor is lower than vacuum level. In NEA surface, vacuum level is lower than that of the bottom of the conduction band. NEA surface makes the polarized electron beam possible, and the beam emittance low employing the light whose energy corresponds to the band gap energy, 1.42 eV at 300 K. The NEA surface is artificially made by deposition of Cs and O_2 on clean p-doped GaAs surface. About 10 % QE can be obtained with 633 nm (about 1.96 eV) light just after activation. Limited operation lifetime is considered due to surface damage by ion back bombardment and deposition of gases. The lifetime issue should be solved for practical use for high brightness operation. Although the lifetime is one of the biggest issues for NEA cathode, NEA surface evolution during the QE decay is not studied well. In this report, we measured temporal evolution of QE spectrum of NEA-GaAs photocathode after activation. We analyzed the spectrum by assuming emission model and extracted potential evolution as explained in detail later.

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PHOTOCATHODE TEST BENCH

Measurement was made with a photocathode test bench as shown in Fig. 1. Zn-doped GaAs ($5.0\times10^{19}/cm^3$) is mounted in the test bench. Light is irradiated to GaAs through a viewing port. To measure photocurrent, the cathode mount is biased by -100 V. The pressure of the bench was kept at about 6.0×10^{-9} Pa by ion pump (160 l/s) and NEG pump (310 l/s). The NEA surface is made by alternating depositions of Cs and O_2 called Yo-Yo method.

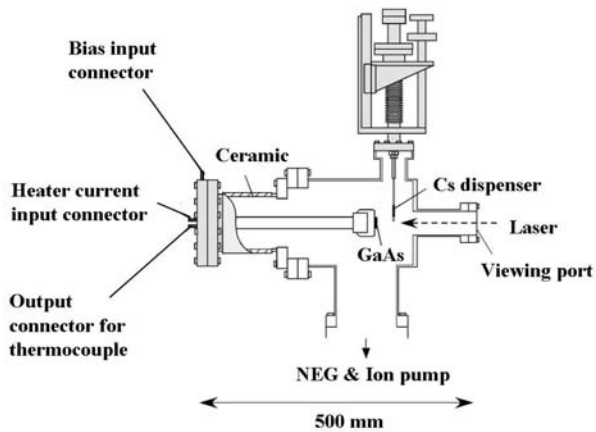

Figure1: Cross section of photocathode test bench [4].

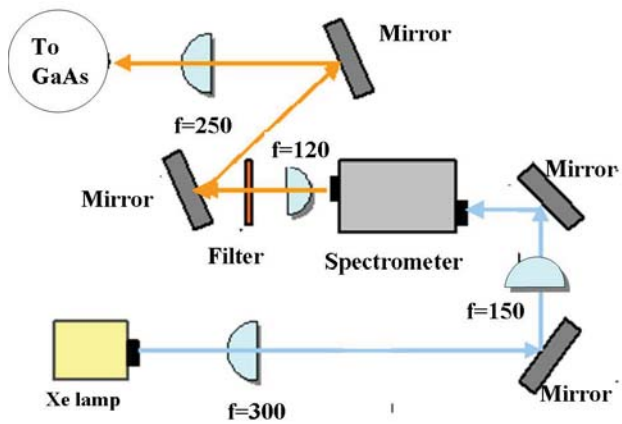

Figure 2: Light source system.

Figure 2 shows light source generating monochromatic light from Xe lamp. Monochromatic light in the wavelength range of 650 – 1000 nm with line width 5.03 nm is obtained by the system.

EXPERIMENTS

Experiment was carried out as follows. At first, clean GaAs cathode is activated by Cs and O_2 deposition. QE is continuously monitored and recorded even during the activation process. After the activation process, we start the iterative measurement process. Up to this point, wavelength was set to 633nm, which corresponds to He-Ne laser wavelength. We define t=0 as when we start the measurement. After the activation, the QE was about 11 %. 35 μW 633nm light was illuminated on the cathode and initially 1.8 μA beam current was extracted. It was decreased down to less than 1% in 80 hours. In every 20 minutes, wavelength was swept from 650 to 1000 nm with 5 nm step. One sweep took 10 minutes.

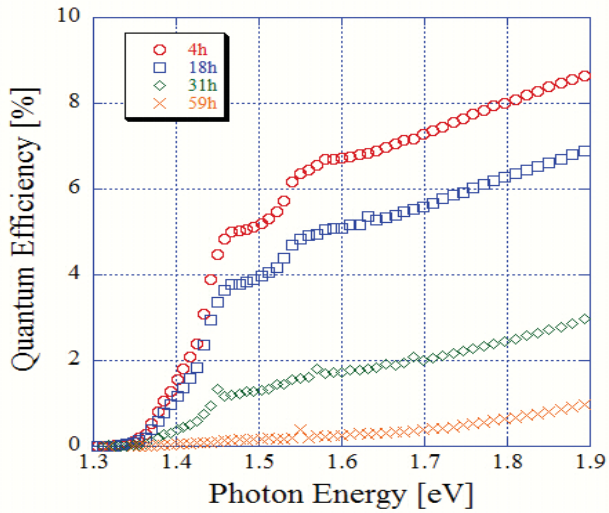

Figure 3: Temporal evolution of QE spectra measured at 4hours (circle), 18 hours (square), 31 hours (diamond), and 59 hours (cross).

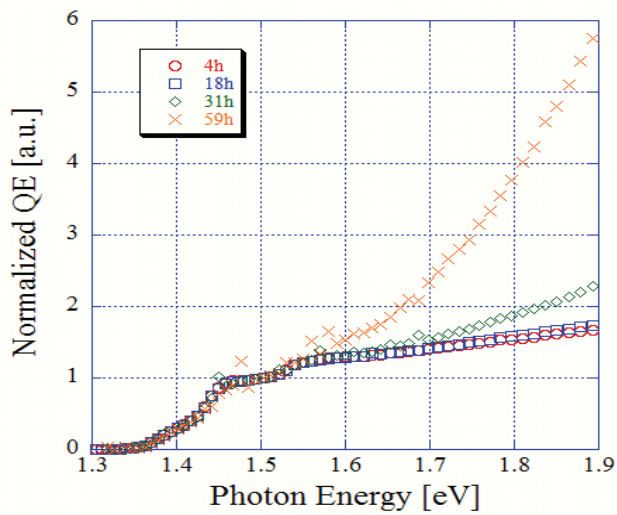

Figure 4: QE spectra normalized by QE at 1.5 eV with same marks as in Fig. 3.

Figure 3 shows QE spectra measured at 4, 18, 31, 59 hours after the activation. QE on all wavelength regions is decreased in time, but the fraction is not flat.

To enhance the inflatness, the spectra are normalized by QE at 1.5 eV of each spectrum as shown in Fig. 4. QE decline is more significant in energy region larger than 1.6 eV. In addition, the spectra shape less than 1.5 eV is almost not changed. This result strongly suggests that the photo-electron emission threshold that is determined by size of NEA, was not changed at all. These properties are analyzed by employing a photo-electron emission model in the next section more quantitatively.

EMISSION MODEL FROM NEA-GaAs

To understand the spectra shape evolution found in our measurement, we developed a photo-electron emission model from NEA-GaAs. The photocathode sample is Zn-doped p-type GaAs. In this model, photo-excitation from the valence band to the conduction band is described by joint density of states. Since there is no hole states in the model, low energy tail below the band gap due to the hole states made by the doping, is not reproduced. That is why we analyzed only data more than 1.45eV energy. After electrons are excited to the conduction band, they drift according to their momentum in the conduction band. The momentum direction is assumed to be random. During the drift, some of electrons are scattered and the scattered electrons are lost. The scattering probability is decided according to the drift length, 1.5 μm [3]. Electrons arrived at the surface are potentially emitted to vacuum. The emission probability is calculated by assuming a potential model representing NEA surface as shown in Fig. 5 [4].

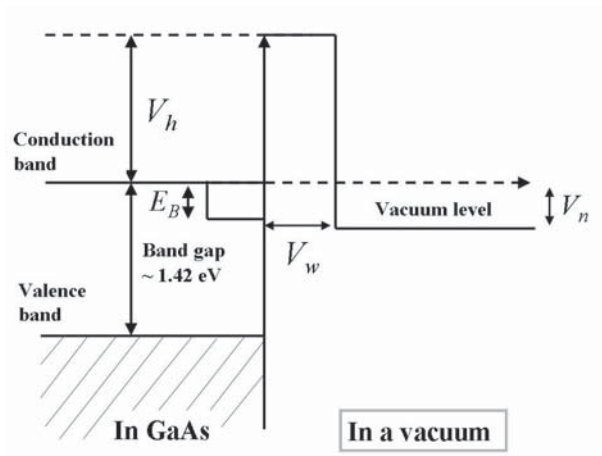

Figure 5: Potential model of NEA surface.

In our measurement, such phenomenon was not observed at all. It means the vacuum level was not changed; at least, it was negative during our measurement. We then fix V_n at -0.1eV in the following calculation.

V_h and V_w are height and thickness of the potential wall. V_n is the size of NEA, i.e. depth from the level of the bottom of the conduction band to the vacuum level. E_B is energy by band bending due to the Zn-doping. Electron emission probability is calculated as tunneling effects with this potential wall based on 1-D quantum dynamics. Figure 6 shows calculated QE spectra for different

vacuum levels (V_n= -0.5, -0.3, -0.1, and 0.1 eV). Other parameters are common: V_h= 1 eV, V_w=0.5 nm, E_B= -0.45 eV. Figure 6 indicates that the spectrum shape is not sensitive to V_n, as long as V_n stays in negative. On the other hand, once V_n goes to positive, the spectrum shape is changed drastically. The photo-electron emission threshold is shifted significantly to higher energy.

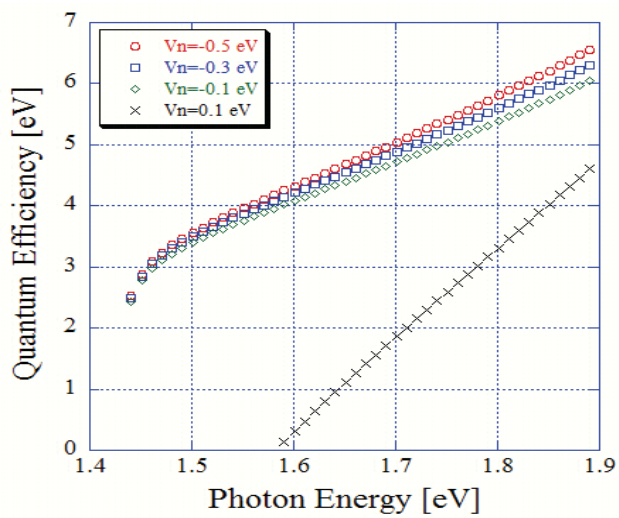

Figure 6: QE spectra calculated by our model.

Figure 7 shows the measured data and the simulation curves. For each spectrum, V_w and V_h are determined by fitting the curve to the data points. The data are shown with the same marks in Fig.4. The fitting was made for the data from 1.45 eV to 1.9 eV. As easily figured out, our model reproduced the measured data well.

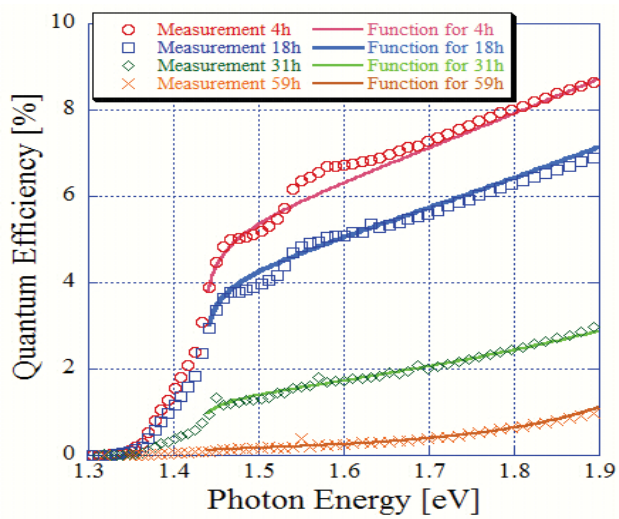

Figure 7: QE spectra with the simulation curves. The data are plotted with the same legends in Fig. 4.

From the analysis, evolution of V_w and V_h are extracted as shown in Fig.8. Horizontal axis shows time in hour since the activation, V_h and V_w are plotted with red circle and blue square, respectively. V_h retained around 1.15 eV until 30 hours. After 30 hours, V_h decreased down to 0.98. V_w, width is gradually increased from 0.4 to 1.0 eV. It is difficult to understand from a physics point of view that the height is decreased in time. Because V_h is changed only 20 % and, in contrast, V_w becomes more than twice of the initial value, the time evolution of V_h is caused by some imperfection of our model. On the other hand, the time evolution of V_w could be significant. As a result of our analysis, QE decay is caused by increment of V_w. V_h and V_n is not changed so much, comparing to V_w.

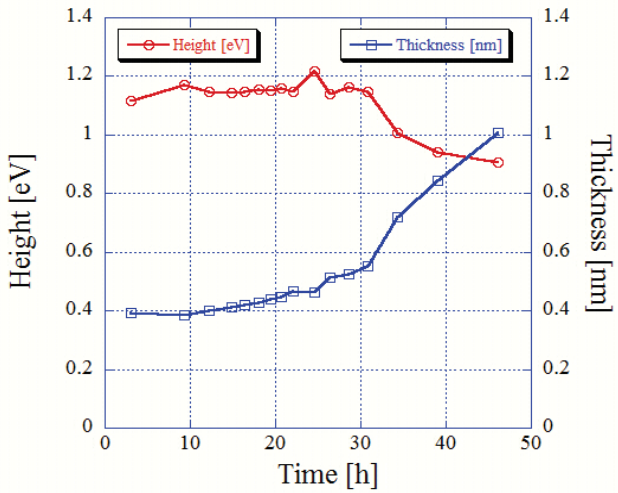

Figure 8: Temporal evolution of V_h and V_w.

SUMMARY

For better understanding of the life time issue, we measured the temporal evolution of QE spectrum of NEA-GaAs photocathode. QE decay was observed in all energy regions, but the decay was not uniform. We analyzed the spectrum based on a model with a potential wall representing NEA surface. Data and calculation are in good agreement. According to the result, V_n was not changed and stayed in negative during the experiment. Decrement of V_h was extracted, but it was likely to be not real. In contrast, V_w was increased significantly and QE spectrum evolution could be explained by increment of V_w.

REFERENCES

[1] T. Rao et al., "Photocathode for the energy recovery linacs", Nucl. Instr. and Meth. A 557 (2006) 124-130.
[2] Chie Shonaka, (2009), "A study of lifetime of GaAs photocathode for high brightness electron source".
[3] Jacwues I. Pankove, "The light process on semiconductor".
[4] H. Rougeot and C. Baud, "Negative Electron Affinity Photoemitters" (L. Marton ed.), Advances in Electronics and Electron Physics 48, (1979).